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Alternative Electrochemical Systems for Ozonation of Water

Hydrogen gas, ozone gas, and ozonated water can be delivered under pressure.

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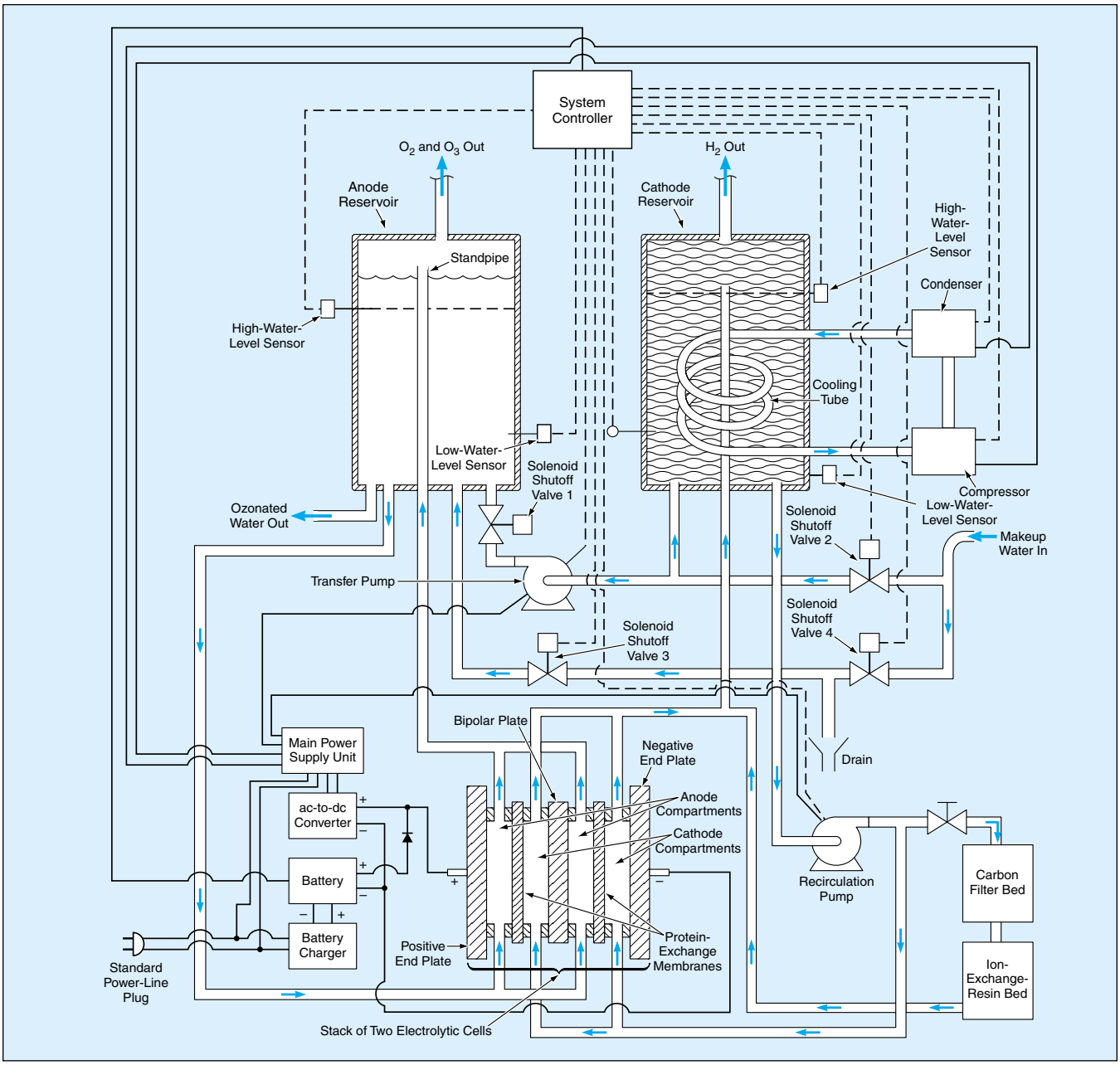
Electrochemical systems that are especially well suited for the small-scale generation of ozone and ozonated water for local use have been invented. These systems can operate with very little maintenance, and the only inputs needed during operation are electric power and water. These systems are closely related to the ones described in "Electrochemical Systems Generate Ozone and Ozonated Water" (MSC-23046), *NASA Tech Briefs*, Vol. 26, No. 3 (March 2002), page 68. Ozonated water produced by these systems can be used in diverse industrial applications: A few examples include sterilization in the brewing industry, general disinfection, and treatment of sewage and recycled water.

The basic principle of operation admits of several alternative system configurations, of which one is depicted schematically in the figure. The heart of the system is a stack of electrolytic cells, each containing a proton-exchange membrane (which serves as a solid electrolyte) sandwiched between a catalytic anode and a catalytic cathode. Preferably, the proton-exchange membrane is made of a perfluorinated sulfonic acid polymer. During electrolysis, a mixture



This **System Generates Ozonated Water**, with an O_2/O_3 gas mixture and H_2 gas as by-products. The water pressure is high enough and the water temperature low enough to maintain an adequate concentration of dissolved ozone for a usefully long time.

of O_2 and O_3 gases is generated at the anode and H_2 is generated at the cathode. Some of the O_3 generated at the anode becomes dissolved in the water. The proportion of O_3 in the O_2/O_3 mixture can be maximized by the selection of suitable electrode materials and the use of a high overpotential. Although the proton-exchange membrane conducts protons, it does not conduct electrons. It is also impermeable by gases; consequently, it maintains separation between the O_2/O_3 mixture evolved at the anode and the H_2 evolved at the cathode.

Water circulates upward through the anode and cathode compartments of the stack of electrolytic cells. Water from the bottom of an anode and a cathode reservoir is gravity-fed to the bottom inlet of the anode and cathode compartment, respectively. From the tops of the anode compartments, the mixture of water and O_2 and O_3 gases and water containing dissolved ozone can flow freely upward, through a standpipe that ends in the anode reservoir, and from the tops of the cathode compartments, the mixture of water and H_2 gas can flow freely upward, through standpipe that ends in the cathode reservoir. The reservoirs double as liquid/gas separators: O_2 and O_3 diffuse out of the water in the anode reservoir, are collected at the top of the reservoir, and are either vented or sent to an ozone-consuming process. Similarly, H_2 diffuses out of the water in the cathode reservoir, is collected at the top of that reservoir, and can be flared, vented, or sent to an H_2-consuming process.

As water is consumed in electrolysis and/or withdrawn from the anode reservoir for external use, makeup water (which must be deionized) is supplied to the system. The addition of makeup water and the circulation of water between the anode and cathode plumbing subsystems is controlled to maintain the desired levels of water in the reservoirs. The control subsystem responds to measurements by high- and low-water-level sensors in the reservoirs and exerts control via several solenoid shutoff valves and a transfer pump. The makeup water can be potable water, in which case it is preferable to introduce a secondary recirculation loop that purifies the water circulated through the cathode compartments and reservoir. Typically, such a recirculation loop includes a recirculation pump in series with a carbon-filter bed followed by an ion-exchange-resin bed.

The system operates with pressures high enough to maintain desired high concentrations of dissolved ozone: The reservoirs and electrolytic cells are preferably designed to operate at gauge pressures up to about 30 psi (≈0.2 MPa). Makeup water is conveniently supplied at a gauge pressure of about 50 psi (≈0.35 MPa): the supply pressure must exceed the reservoir pressure in order to make the water flow into the reservoirs.

A refrigeration subsystem includes a compressor, a condenser, and a cooling tube coiled within the cathode reservoir. This subsystem removes the heat introduced by electrolysis and maintains the water in the system at or below a set temperature, which is typically about 35 °C: This is an important function because lowering the temperature extends the lifetime of the ozone dissolved in the water.

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Refer to MSC-23045, volume and number of this NASA Tech Briefs *issue, and the page number.*

Interferometer for Measuring Displacement to Within 20 pm

Errors are reduced by suppressing effects of polarization leakage and thermal expansion.

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An optical heterodyne interferometer that can be used to measure linear displacements with an error ≤20 pm has been developed. The remarkable accuracy of this interferometer is achieved through a design that includes (1) a wavefront split that reduces (relative to amplitude splits used in other interferometers) self interference and (2) a common-optical-path configuration that affords common-mode cancellation of the interference effects of thermal-expansion changes in optical-path lengths.

The most popular method of displacement-measuring interferometry involves two beams, the polarizations of which are meant to be kept orthogonal upstream of the final interference location, where the difference between the phases of the two beams is measured. Polarization leakages (deviations from the desired perfect orthogonality) contaminate the phase measurement with periodic nonlinear errors. In commercial interferometers, these phase-measurement errors result in displacement errors in the approximate range of 1 to 10 nm. Moreover, because prior interferometers lack compensation for thermal-expansion changes in optical-path lengths, they are subject to additional displacement errors characterized by a temperature sensitivity of about 100 nm/K. Because the present interferometer does not utilize polarization in the separation and combination of the two interfering beams and because of the common-mode cancellation of thermal-expansion effects, the periodic nonlinear errors and the sensitivity to temperature changes are much smaller than in other interferometers.

The present interferometer (see figure) makes use of two stable, collimated laser beams — one at a frequency of f_0, the other at the slightly different frequency of $f_0+\delta f$. The f_0 wavefront is split into two or more sections by a retroreflective reference device that could be, for example, a truncated corner-cube reflector or a mirror with holes. The portion of the f_0 wavefront reflected by the reference device serves as reference wavefront. The portion of the f_0 wavefront not reflected by the reference device is directed to a target in the form of a retroreflector. The target is mounted on the object, the displacement of which one seeks to measure relative to the reference device.

The light reflected by the target travels back through the optical system alongside the retroreflected reference light. Along the way, both the target